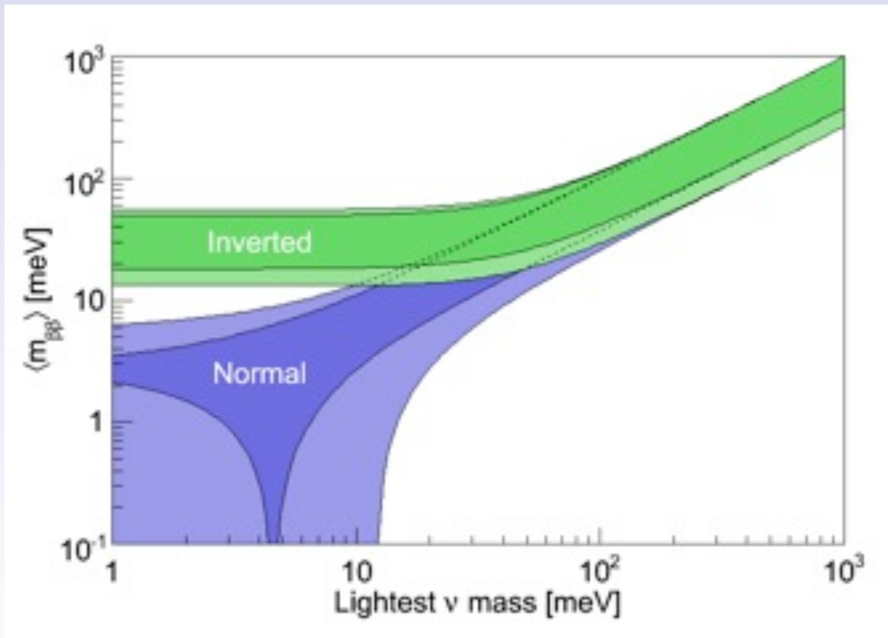
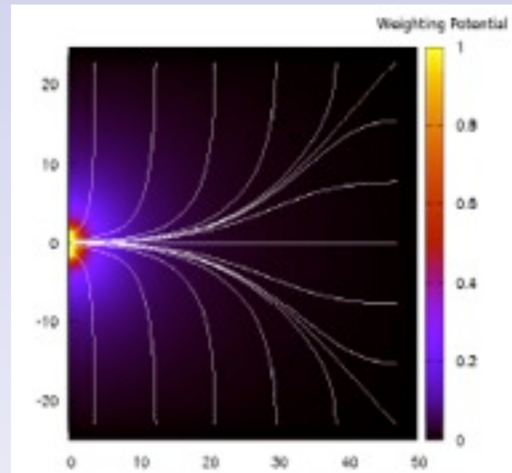
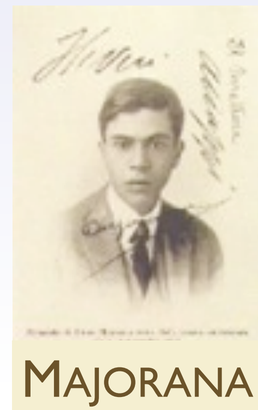
A 1-tonne ^{76}Ge Neutrinoless Double Beta Decay Experiment





GERDA



THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

October 1, 2009
Lead, SD

J.F. Wilkerson
DUSEL Science Workshop

Searching for 0νββ

0νββ decay probes fundamental questions:

- Neutrino properties — the only practical technique to determine if neutrinos are their own anti-particles — Majorana particles.
- Lepton number violation (LNV) — might Leptogenesis be the explanation for the observed matter - antimatter asymmetry?

The observation of 0νββ would demonstrate Majorana nature of ν and LNV

If 0νββ is observed:

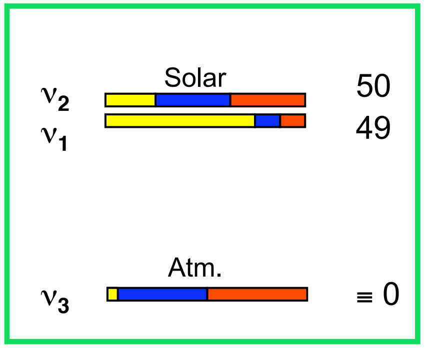
- Provides a promising laboratory method for determining the absolute neutrino mass scale that is complementary to other neutrino mass measurement techniques.
- Measurements in a series of different isotopes can potentially help reveal the nature of the lepton number violating process(es).

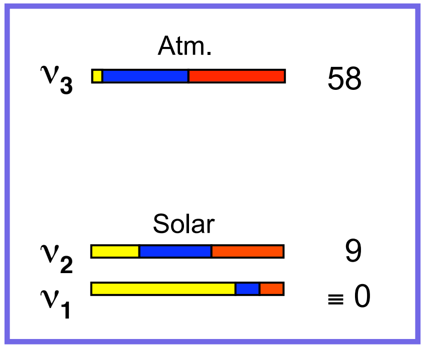
Extraction of ν mass and understanding the LNV process(es) will require significant reliance on both nuclear and particle physics.

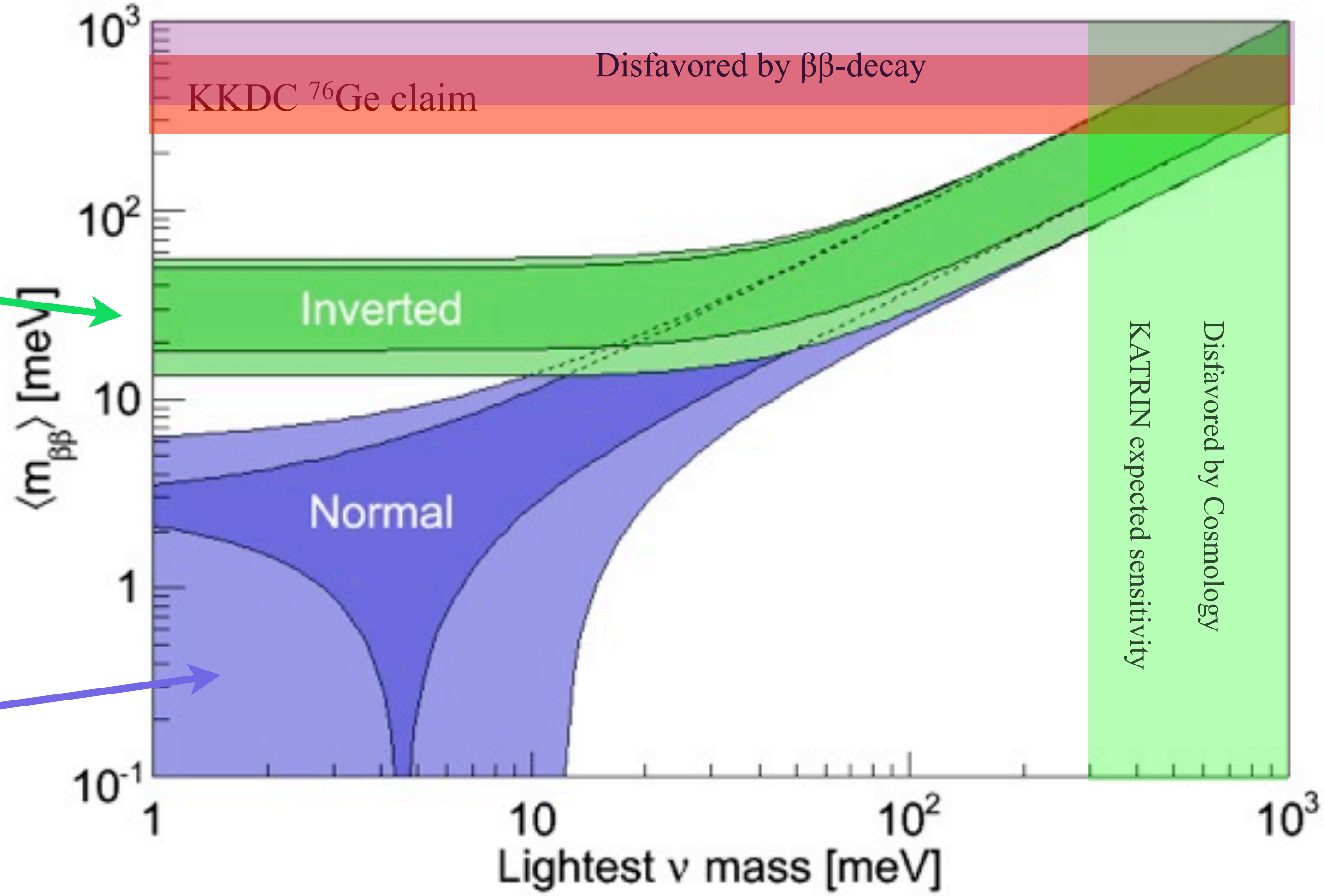
0νββ Decay Sensitivity to <mββ>

Assumes Lepton Violating mechanism is light Majorana neutrino exchange

$$m_{\beta\beta} = \left|\sum_i U_{ei}^2 m_i\right| = \left|c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$



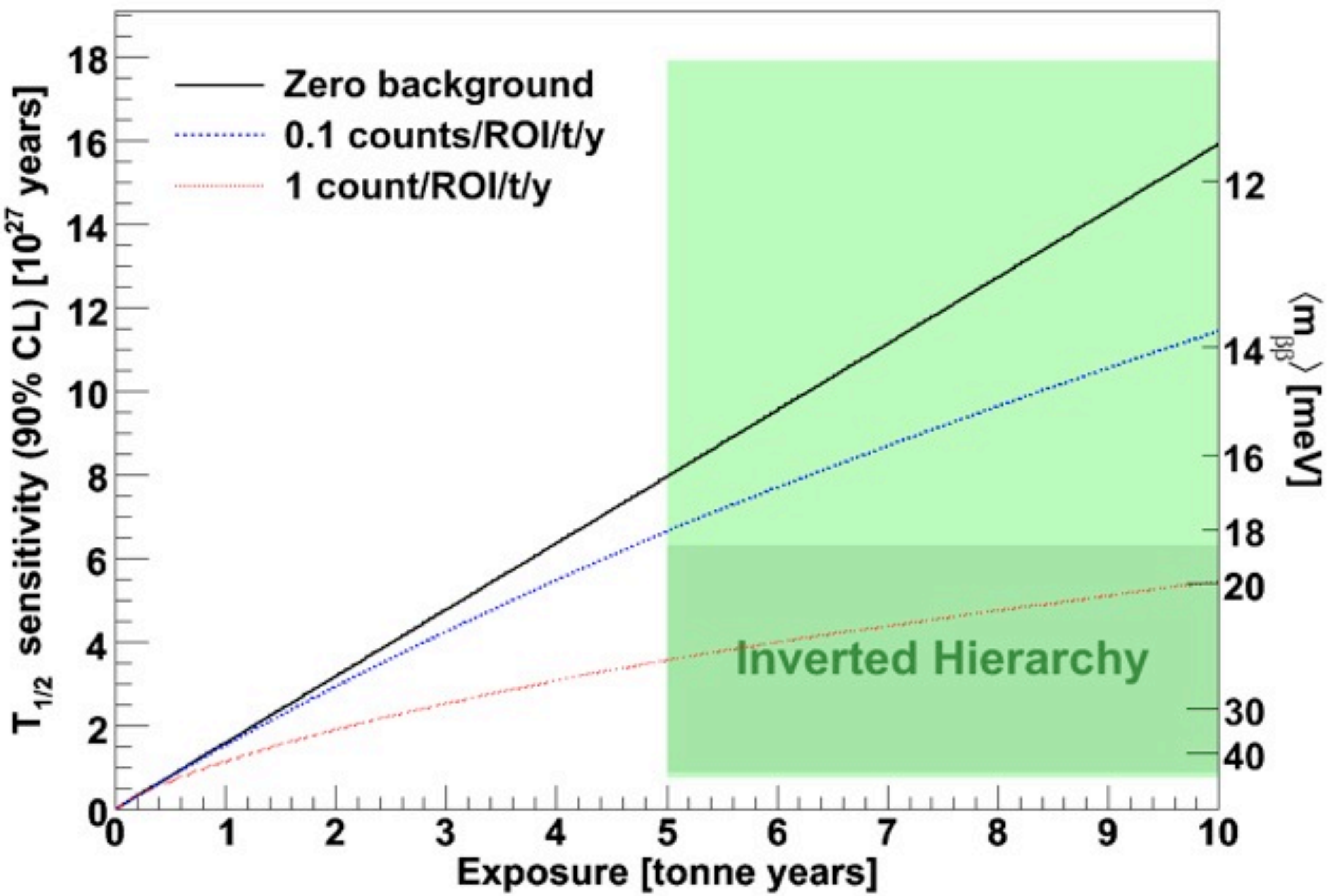




Sensitivity vs. Mass

1-tonne ^{76}Ge

$T_{1/2}^{0\nu} = \ln(2) N \varepsilon t / UL(B)$



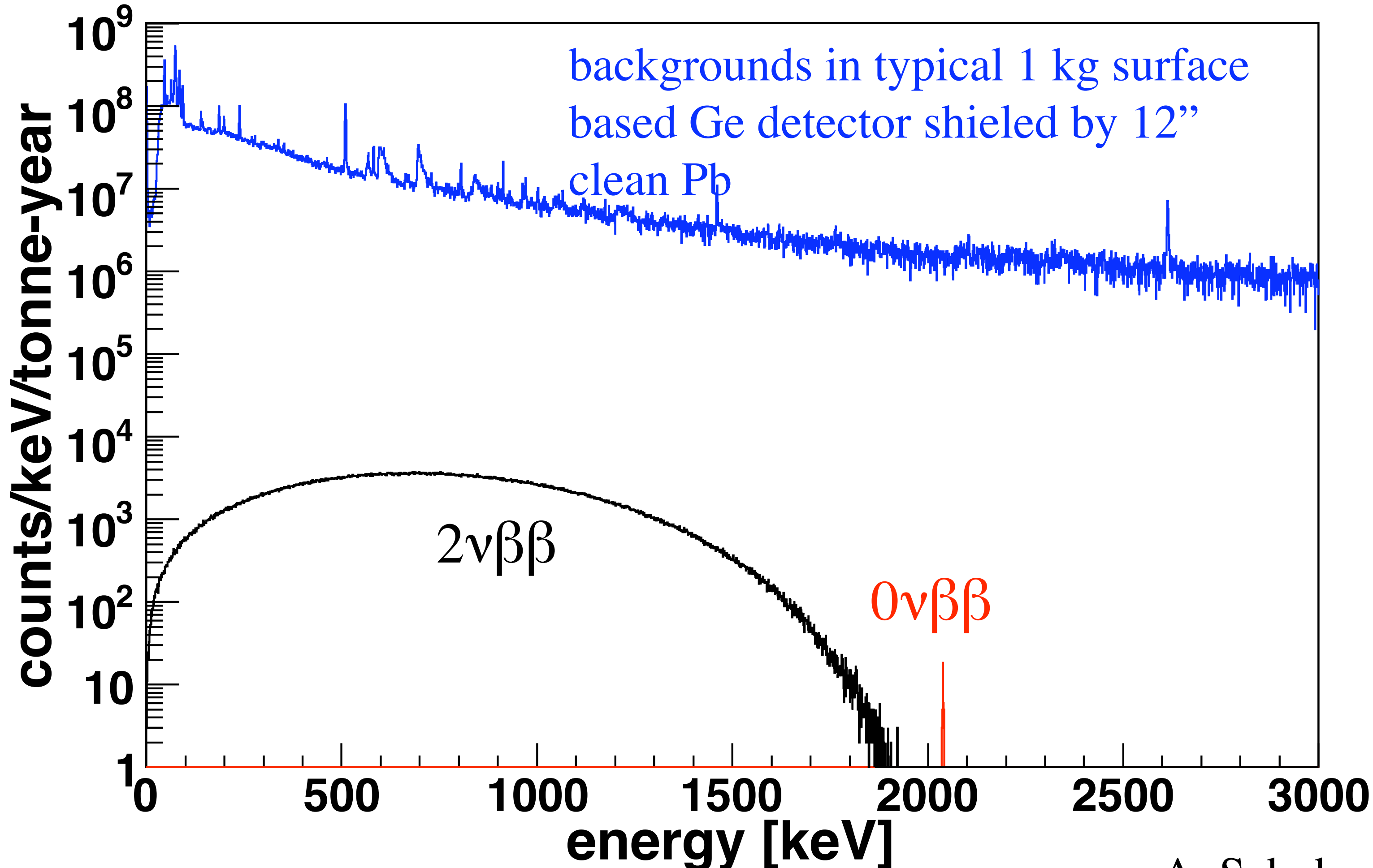
Backgrounds & Sensitivity to 0νββ

- Backgrounds - 1-tonne scale experiments are striving for backgrounds in the 0νββ region of **cnts/t-y**.
  - Requires materials with sub μBq/kg level radioimpurities.
    - Not possible to achieve this sensitivity with direct radioassays
  - "New background regimes" -- background sources that could previously be ignored
    - e.g. : very weak (n,n',gamma) lines

- Scalability - Need to move from current ~10 kg scale to 1000 kg scale.
  - Requires cleanliness at requisite scale.

- Signal and Background Characterizations
  - Reliably simulate the entire observed spectrum.
  - Demonstrate capability to measure the 2νββ spectrum
  - Search for excited state decays for 0νββ and 2νββ

1ct/tonne-year in context



A. Schubert

0νββ half-life chosen to be 10x current limit

A 1-tonne ^{76}Ge Experiment

The MAJORANA Collaboration and the GERDA Collaboration are working towards developing a single ~1 tonne scale ^{76}Ge 0νββ-decay experiment that could potentially be one of the flagship Initial Suite of Experiments (ISE) to be sited at DUSEL Homestake at ~4850’ or deeper.

– 1-tonne Science goals:

- Determine the nature of the neutrino, Majorana or Dirac.
- Test the fundamental symmetry of lepton number conservation.
- Probe absolute neutrino mass at a sensitivity of 20-40 meV (the inverted hierarchy region).
- Seek to understand the origin of particle masses.
- Search for Dark Matter candidates.

Using ^{76}Ge to search for 0νββ

^{76}Ge offers an excellent combination of capabilities and sensitivities.

- Ge as source & detector.
- Elemental Ge maximizes the source-to-total mass ratio.
- Intrinsic high-purity Ge diodes.
- Reasonably slow 2νββ rate ($T_{1/2}$ = 1.4 × 10^{21} y).
- Reasonable nuclear matrix element $|M^{0\nu}|$=2.22
- Demonstrated ability to enrich from 7.44% to ≥ 86%.

- Excellent energy resolution — 0.16% at 2.039 MeV, 4 keV ROI
- Powerful background rejection.
  Segmentation, granularity, timing, pulse shape discrimination
- Best limits on 0νββ - decay used Ge (IGEX & Heidelberg-Moscow)
  $T_{1/2}$ > 1.9 × 10^{25} y (90%CL)
- Well-understood technologies
  - Commercial HPGe diodes
  - Large Ge arrays (Gammasphere, TIGRESS, AGATA, GRETINA)

1-tonne scale Ge Detector S4 CA

MAJORANA Collaboration & members from GERDA

Description: advances the technical design of a tonne-scale ^{76}Ge based neutrinoless double beta decay experiment that might be a candidate for installation at a later stage in DUSEL

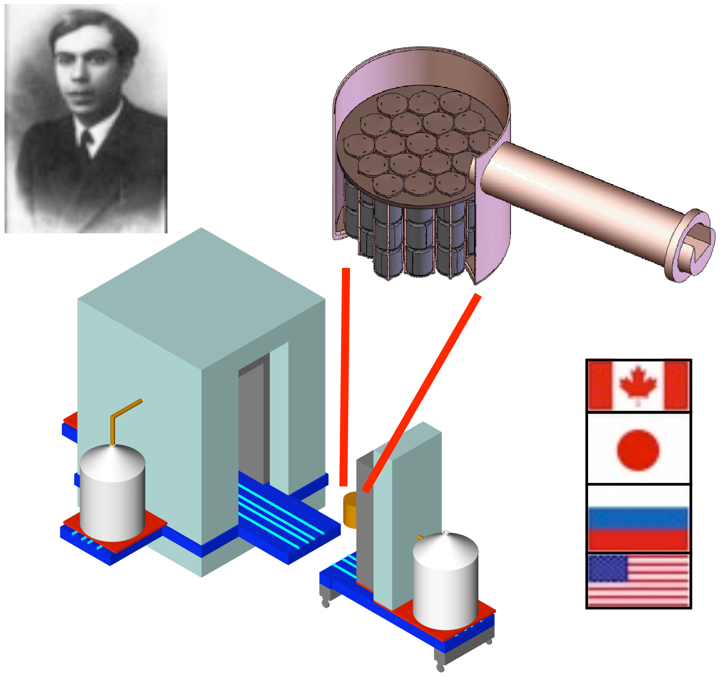
Goals:

- develop a preliminary design for an experiment that could be implemented at DUSEL
- conduct R&D to better understand the recycling options that need to be implemented to maximize the use of the enriched ^{76}Ge material.

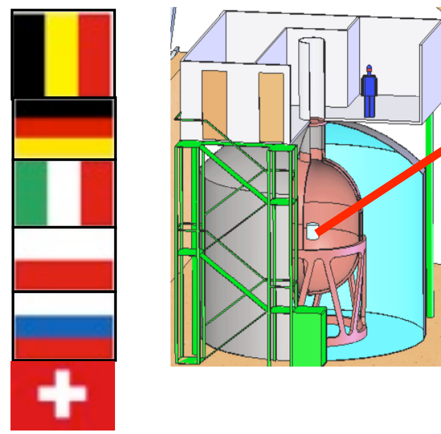
Builds on and is complementary with GERDA Phase I/II and MAJORANA DEMONSTRATOR activities.

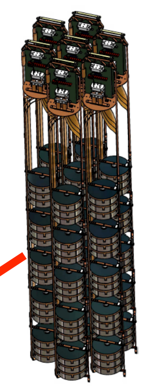
^{76}Ge - MAJORANA and GERDA

Joint Cooperative Agreement:
Open exchange of knowledge & technologies (e.g. MaGe, R&D)
Intention to merge for larger scale 1-tonne exp.
Select best techniques developed and tested in GERDA and MAJORANA



GERDA





- ^{enr}Ge modules in electroformed Cu cryostat, Cu / Pb passive shield
- 4π plastic scintillator μ veto
- DEMONSTRATOR: 30 kg ^{enr}Ge/30 kg ^{nat}Ge

- ^{enr}Ge array submersed in LAr
- Water Cherenkov μ veto
- Phase I: ~18 kg (H-M/IGEX xtals)
- Phase II: +20 kg segmented xtals

The MAJORANA Collaboration

Note: Red text indicates students

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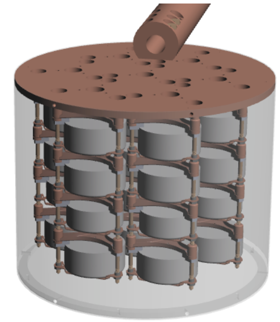
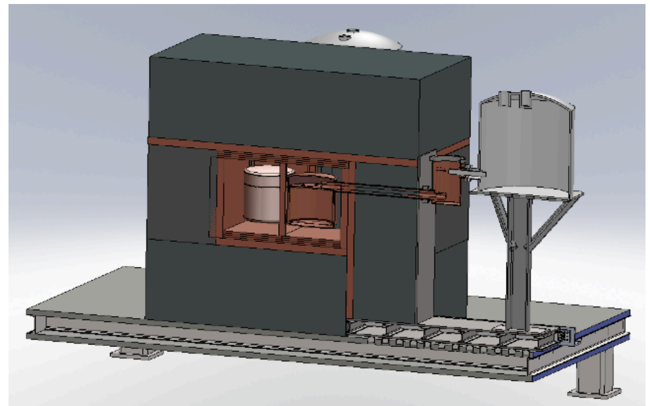
Mike Miller, R. G. Hamish Robertson, Alexis Schubert, Tim Van Wechel

The MAJORANA DEMONSTRATOR

- 60-kg of Ge detectors
  - 30-kg of 86% enriched ^{76}Ge crystals and 30-kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.

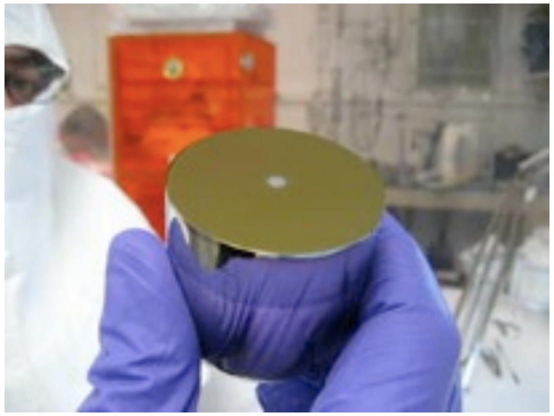


- 3 independent modules
  - ultra-clean, electroformed Cu cryostats
  - ~20 kg of detectors per cryostat
  - naturally scalable

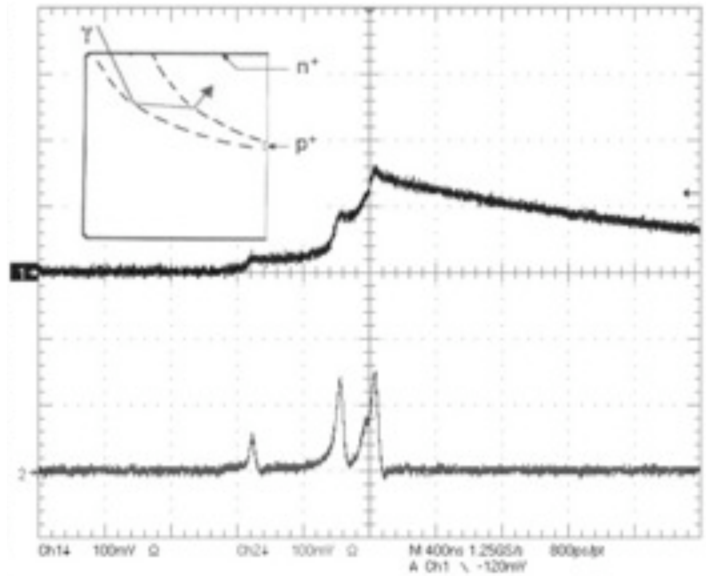


- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto
- Located underground 4850’ Sanford Lab
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV) **~ 1 count/ROI/t-y** (after analysis cuts)

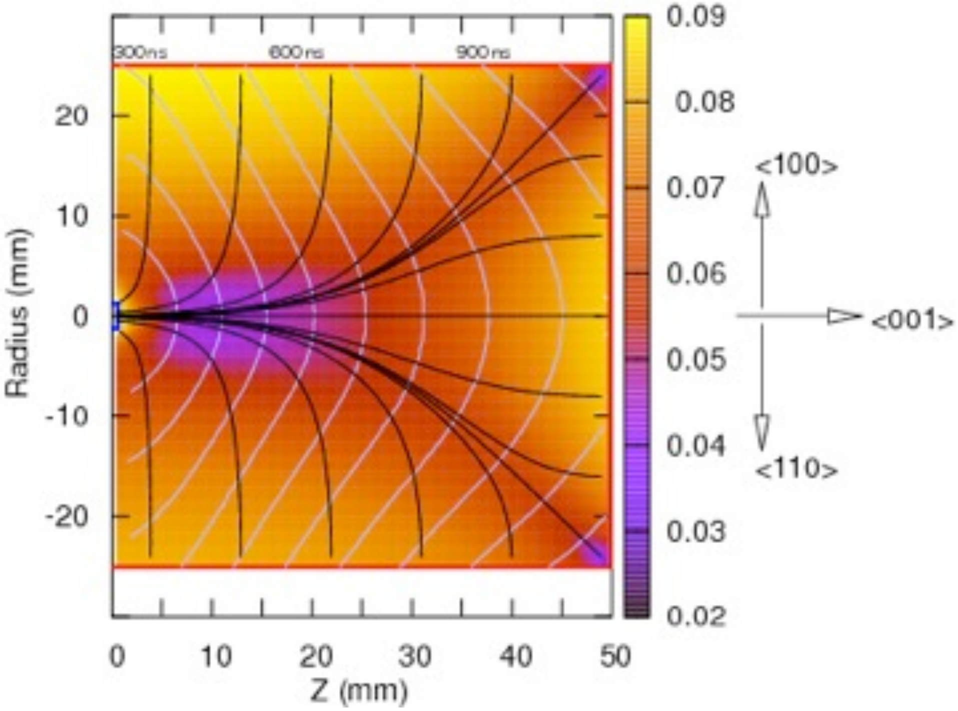
P-type Point Contact Detectors



Barbeau et al., JCAP 09 (2007) 009; Luke et al., IEEE trans. Nucl. Sci. 36 , 926(1989).



Hole vdrift (mm/ns) w/ paths, isochrones



The GERDA Collaboration

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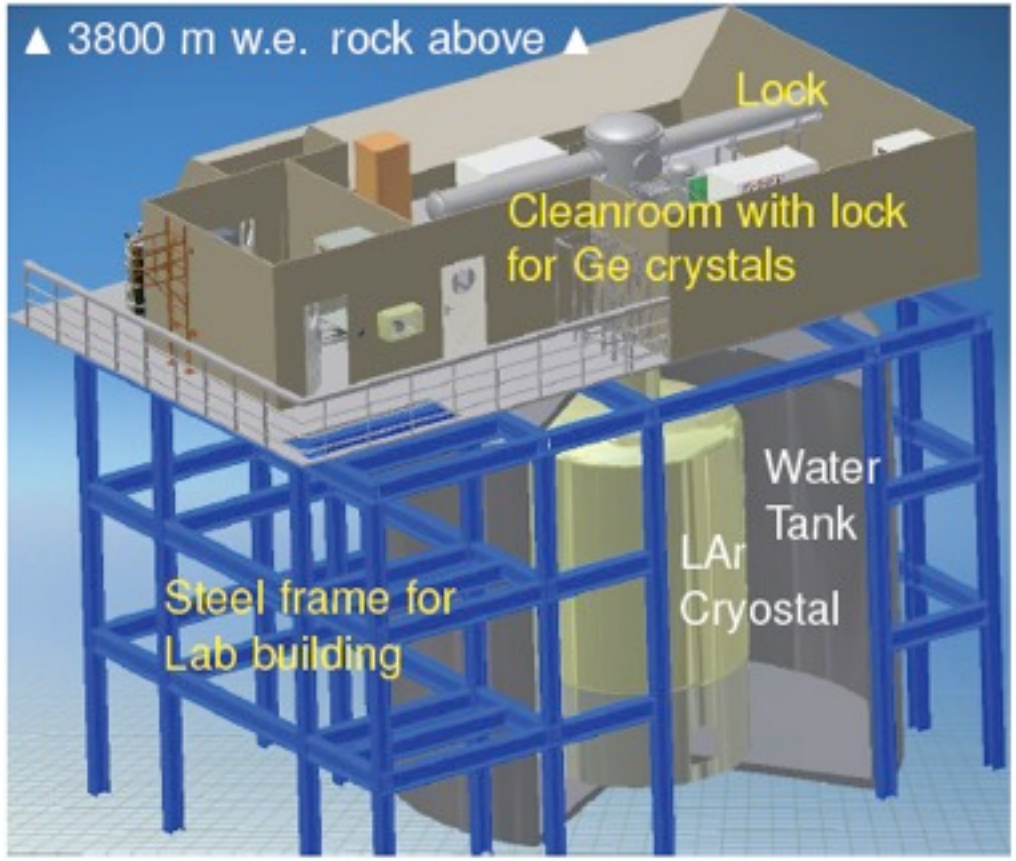
GERDA Phases I and II

Phase I

- Use ^{76}Ge enr. diodes (HdMo & IGEX)
- Scrutinize KDKC.
  If claim true, expect 13 signal / 3 bck.
  [10 keV window at 2 MeV, 4 keV FWHM]
- Active M: 17.9 kg
- Exposure: $\sim$ 30 kg·y
- bck: 0.01 cts/(keV·kg·y)
- $T_{1/2}: 2 \cdot 10^{25}$ y

Phase II

- Add new enriched ^{76}Ge detectors
- 37.5 kg enriched ^{76}Ge available.
- Active M: $\geq$ 40 kg (yield unknown. R&D on detector technology ongoing)
- Exposure: $\sim$ 100 kg·y
- bck: 0.001 cts/(keV·kg·y)
- $T_{1/2}: 15 \cdot 10^{25}$ y



Located underground at
Gran Sasso (LNGS)

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Located underground at Gran Sasso (LNGS)

1-tonne scale Ge: Project Objectives

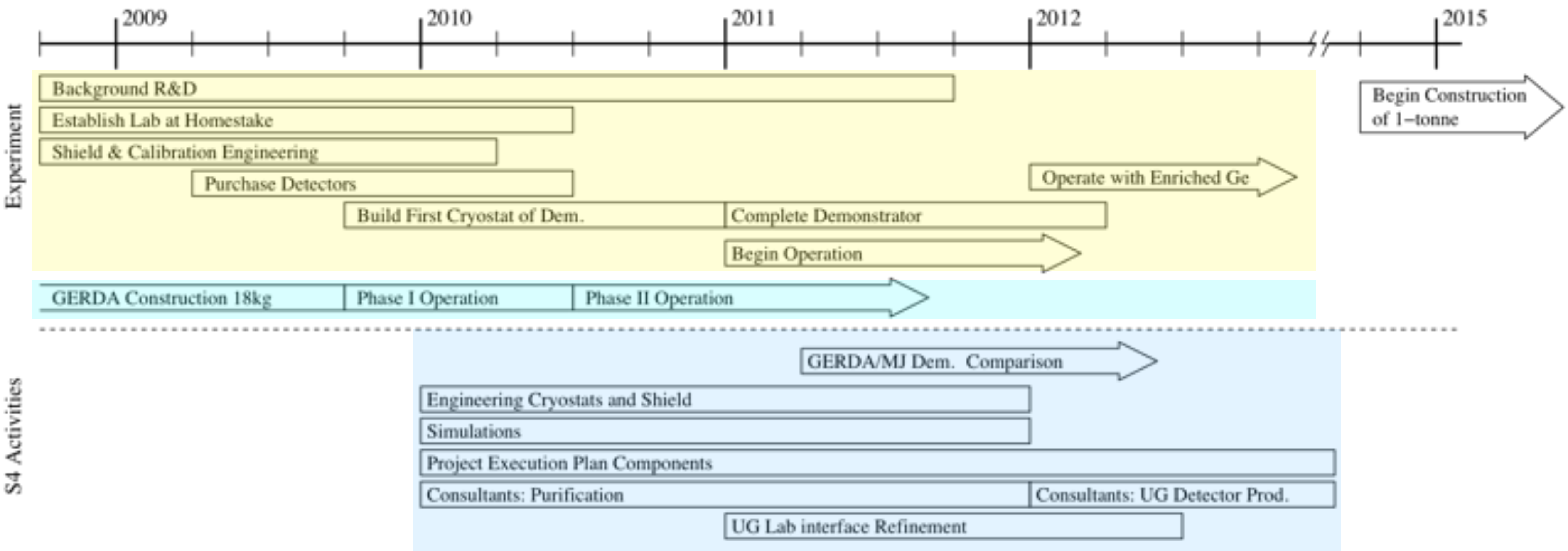
1) Ge acquisition
   i. Define the acquisition plan for the enriched ^{76}Ge.
   ii. Perform R&D on Ge recycling options during the Ge refinement stage.
   iii. Understand large-scale Ge detector production, in particular implementation of efficient material recycling.
   iv. Evaluate need to produce the detectors underground to reduce cosmogenically produced backgrounds.

2) Assessment of upcoming Majorana Demonstrator and GERDA Phases I/II results.
   i. Assess shielding and cryostat designs based on both simulations and measurements.
   ii. Develop preliminary 1-tonne shield and cryostat designs based on current Demonstrator and GERDA designs.
   iii. Develop specifications for choosing between shield and cryostat designs.

3) Project Plan
   i. Develop the major elements of the Work Breakdown Structure for the tonne-scale experiment.

4) Education and Outreach
   i. Create and maintain a series of public exhibits related to particle and nuclear astrophysics exhibits in partnership with the Morehead Planetarium and Science Center (MPSC).

1-tonne scale Ge: Schedule



Summary

- Path towards a 1-tonne ^{76}Ge 0νββ
  - GERDA Phase I/II
  - MAJORANA DEMONSTRATOR
  - S4 1-tonne Cooperative Agreement
  - CUBED study of growing Ge crystals underground
- The observation of 0νββ-decay would demonstrate Lepton number violation and indicate that neutrinos are Majorana particles - constituting a major discovery.
- If 0νββ-decay is observed then it opens an exquisitely sensitive window to search for physics beyond the Standard model.